Experimental Particle Physics Group(Physics,Annual Report(from April 2003 to March 2004))

Experimental Particle Physics Group

(http://www.awa.tohoku.ac.jp)

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Research Activities

I. The KamLAND group

(*Atsuto Suzuki, Jumpei Shirai, Fumihiko Suekane, Kunio Inoue, Masayuki Koga, Yasuhiro Kishimoto, Jean-stephane Ricol, Fabrice Piquemal, Koichiro Furuno, Tadao Mitsui, Masakazu Motoki, Hiroshi Ogawa, Alexandre Kozlov, Kyoko Tamae Sanshiro Enomoto, Hideki Watanabe, Haruo Ikeda, Kyo Nakajima, Itaru Shimizu, Koji Eguchi, Tatsuo Maeda, Kiyoshi Ikeda, Yotaro Koseki, Kentaro Owada, Ken'ichi Tada, Takayuki Araki, Koichi Ichimura, Yusuke Tsuda*)

An evidence for the reactor neutrino disappearance obtained in the first KamLAND result excluded all but the LMA solution to the solar neutrino problem under the CPT conservation. If combined with the solar neutrino measurements, it means the longstanding solar neutrino problem has been finally solved. The allowed region from the solar + KamLAND global analysis has two separated bands in the LMA region (LMA1 and LMA2 for $7 \times 10^{-5} eV^2 < \Delta m^2 < 2 \times 10^{-4} eV^2$). In order to improve the precision of oscillation parameters more statistics has been acquired. Total exposure to the reactor neutrino flux has been increased from 162 ton-year to 766.3 ton-year due to 3 times longer live time and 33% increased fiducial volume. The observed number of $\bar{\nu}_e$ events is 258 while expected without oscillation is 365.2 ± 23.7 signal and 7.5 ± 1.3 background events. The confidence level for reactor $\bar{\nu}_e$ disappearance is now 99.995%. In addition to this disappearance, energy spectrum has been investigated with improved statistics. The observed energy spectrum is consistent with the so-called LMA1 solution but is inconsistent with a scaled no oscillation spectrum at the 99.9% confidence level. This is an evidence of spectral distortion. If one plots the data with L_0/E where L_0 is the effective baseline and is a constant value, we see clear oscillatory behavior of neutrino survival probability as expected by the neutrino oscillation hypothesis. The shape disfavors the other hypotheses, decay at 95% level and decoherence at 94% level. The χ^2 values obtained are 18.3 (oscillation), 30.1 (decay) and 28.6 (decoherence), respectively all with 18 degree of freedom. Considering difference of χ^2 values, oscillation is favored over the other hypotheses at more than 99% level. Even in the oscillation parameters, the LMA1 is favored over the LMA2 and LMA0, whose Δm^2 is below LMA region, at 99.6% and 94% confidence level, respectively. Now, KamLAND alone can claim an observation of neutrino oscillation with reactor neutrinos. If combined with solar results and performed a global analysis, we obtain neutrino oscillation parameters as $\Delta m^2 = 8.2^{+0.6}_{-0.5} \times 10^{-5}\mathrm{eV}^2$ and

$\tan^2\theta = 0.40^{+0.09}_{-0.07}$. The precision of mass squared difference has been dramatically improved by the new KamLAND result.

Another high sensitivity search for $\bar{\nu}_e$ above the reactor neutrino energy region has also been carried out. Possible phenomena of resonant spin flavor transition (RSFP) of Majorana neutrinos and neutrino decay are examined in the energy range of $8.3 < E_\nu < 14.8$ MeV, where a relevant neutrino source is the solar neutrinos. We have analyzed 280 ton-year exposure data and observed zero events where 1.1 ± 0.4 events are expected. This null signal gives an upper limit of $\bar{\nu}_e$ flux as $3.7 \times 10^2 \mathrm{cm}^{-2}\mathrm{sec}^{-1}$ at 90% confidence level assuming constant fraction of ^{8}B neutrinos are converted to $\bar{\nu}_e$. This limit corresponding to the constant fraction of 2.8×10^{-4} is more than 30 times better than the previous best upper limit from Super-Kamiokande. This result gives constraints on the RSFP+oscillation hybrid model or neutrino decay hypothesis. Other study of supernova relic neutrino search is ongoing.

KamLAND is a multi-purpose neutrino detector and the next physics targets are an observation of neutrinos from the earth and spectral measurement of the low energy solar neutrinos. Current KamLAND performance is good enough to observe geo-neutrinos and its result will appear shortly with further improved statistics. However, the measurement of low energy ^{7}Be solar neutrino requires 10^{4-6} reduction of radio active impurities (^{210}Pb and ^{85}Kr for now) in the liquid scintillator. We believe some kinds of bubbling method are effective to remove ^{85}Kr noble gas component. And vigorous R&D has been performed to invent a method for the ^{210}Pb reduction. It turned out that the water extraction we already have for the K, U and Th removal from the present KamLAND liquid scintillator, doesn't work satisfactorily. An adsorption method with fine-grained silica gel can remove lead by factor 20 and 5 times distillation successfully reduced lead by more than factor 2000. Combination of these two methods looks very promising and further studies are continuing to make a successful detection of the low energy solar neutrino flux in a few years.

II. BELLE group

(*Akira Yamagushi, Hitoshi Yamamoto, Tadashi Nagamine, Osamu Tajima, Peter Schoenmeier, Fumiaki Handa, Itaru Higuchi, Yoshinari Mikami, Yosuke Yusa, Manabu saigo, Takahiro Kato, Satoru Nozaki, Masatsugu Uneda*)

KEK-B collides a 8 GeV electron beam with a 3.5 GeV positron beam generating about 100 million B meson pairs per year. This is one of the two such machines in the world - the other one is operating in California and called PEP-2. As of June 2004, KEK-B has exceeded the design luminosity to achieve 1.4×10^{34} /cm^{2}s which is about 50% larger than that achieved by

PEP-2.

The main subject of the experiment is to study CP violating effects on the B meson system. One of the bench-mark measurement is the determination of $\sin 2\phi_1$ using charmonium modes. The measured value $\sin 2\phi_1 = 0.733 \pm 0.057 \pm 0.028$ turned out to be consistent with the prediction of the standard model. Recently, we have seen that the value of $\sin 2\phi_1$ measured for ϕK_S final state is not consistent with that measured by charmonium modes by 3.5 sigmas. If this holds, it signifies a new physics beyond the standard model. Belle has recently discovered a new charmonium-like state $X(3872)$ which had not been predicted by theory, and provided critical measurements to determine the quantum numbers of the newly-discovered narrow D_{sJ} states. Belle is also a rich field for tau and charm physics.

One of our hardware responsibilities are the RPC (resistive plate counter) used for detection of muons and neutral hadrons. This is done in collaboration with Tohoku-Gakuin University, Osaka City University, KEK, Aomori University, Princeton University, and Verginia Technology. The construction of the endcap RPC's was successfully completed at Tohoku University. It has been operating well, providing Belle with the indispensable muon identification as well as that for neutrons and K_L.

For the last three years, we have been working with KEK to design and fabricate the region of machine detector interface. Careful study and design efforts are critical in suppressing the beam-induced backgrounds so that the Belle detector can operate with high luminosity and also to reduce the beam pipe radius from 2 cm to 1.5 cm for a better vertex resolution. We have installed the new IR beampipe last summer, and the measured beam background was found to be consistent with the expectation. A Tohoku research fellow, Tajima, is responsible for the synchrotron-induced background study and also working on the fabrication of the IR beampipe and its spare. The vertex resolution in the beam direction was found to improve to about 2/3 of the old value whose physics benefits are to appear in the coming years.

The signal of the first observation of charm radiative decay $D \to \phi\gamma$ was established by a M2 student Fujisawa and the analysis was completed by Tajima. The result was reported at the news release at the international high energy physics conference at Fermilab last year. Higuchi has been in charge of the $J/\Psi K_L$ mode for the $\sin 2\phi_1$ analysis which is one of the two most important modes involved, and has graduated recently. Mikami has done the inclusive measurements of the new D_{sJ} states more or less single-handedly, and now working on a $|V_{ub}|$ measurement using D_S meson production in B decay. Yusa is now writing his Ph.D. thesis on rare tau decays such as $\tau \to 3$ leptons. A M2 student Nozaki is working on another tau analysis for his master thesis. A measurement of the CP-violating angle ϕ_3 using the DK

mode is studied by a D1 student Saigo and a M1 student Kikuchi. A M1 student Ando is now working on the important rare mode $K\nu\bar{\nu}$ using the full-reconstruction tagging technique.

We are also involved in the linear collider project where Yamamoto acts as the representative of the Asian section of the world-wide study of the physics and detector for linear collider. A M1 student Fujikawa is working on the simulation study together with Nagamine. A M2 student Uneda and a research associate Peter Schoenmeier are working on a silicon pixel R&D for the linear collider.

III. Super-Kamiokande group

(*K.Inoue, T.Hasegawa and Y.Gando*)
Atmospheric neutrinos

The recovery of Super-Kamiokande has been successfully completed with reduced number of inner PMTs from 11146 to 5182. Atmospheric neutrino analysis is still early stage but its performance is demonstrated as valuable for K2K experiment. SK-II has already acquired 311.5 live-days of data and its energy scale is well-controlled and particle identification is also successful. The preliminary result obtained from SK-II are consistent with SK-I. Final analysis for SK-I is in progress. Total number of atmospheric neutrino event acquired in SK-I is about 14,000 and 11,530 events are used for the oscillation analysis. The oscillation analysis has been performed for various data subset and all of them (sub-GeV low, sub-GeV high, Multi-GeV, PC, Multi-ring and Up-going muon) give the consistent allowed oscillation parameters. Combined result gives allowed oscillation parameters as $\sin^2 2\theta > 0.92$ and $1.5\times 10^{3} < \Delta m^2 < 3.2\times 10^{-3}\mathrm{eV}^2$ at 90% C.L.. A new analysis looking at the sinusoidal pattern of flavor transition probability as a function of L/E. A dip consistent with a neutrino oscillation hypothesis was seen in the observed L/E distribution. The distribution disfavors neutrino decay or decoherence hypothesis at about 99.9% C.L. and thus is an evidence for neutrino oscillation signature in atmospheric neutrinos. The analysis also gave better mass difference determination of $1.9\times 10^{-3} < \Delta m^2 < 3.0\times 10^{-3}\mathrm{eV}^2$ at 90% C.L..
Solar neutrinos
Total number of solar neutrino events observed during the SK-I 1496 live-days amounts to $22,400 \pm 230$ events above 5 MeV. The ratio to the expected number of events from SSM2004 is $0.406 \pm 0.004^{+0.014}_{-0.013}$. High precision study of spectrum distortion and time variation have been done on this data set. Day/Night asymmetry obtained by unbinned method is $A_{DN} = -1.8 \pm 1.6^{+1.3}_{-1.2}\%$ and the spectrum prefers smaller Δm^2 and larger $\tan^2\theta$ compared with the global best fit parameters. Assuming ^{8}B total flux of

the SSM predictions, only the LMA solution is preferred with even SK-I alone. Another effort went to extend the energy window to lower side. Solar neutrino signal in 4.5-5.0 MeV (total energy) bin (relevant to see spectrum distortion at the LMA solution) was newly obtained. A preliminary analysis has been performed for the SK-II data and gave a consistent result with SK-I. SK-III with full PMT installation is expected to start in March 2006. Accumulating low energy data in SK-III, we will hopefully observe definite energy spectrum distortion if it should be there.

IV. K2K

(*T.Hasegawa*)

After rebuilding the far detector, Super-Kamiokande,the KEK to Kamioka long-baseline neutrino experiment(K2K) resumed its data taking from December 2002. Accumulated protons on target(POT) for these period corresponds to 4.1×10^{19} which is almost same as POT accumulated before Super-Kamiokande accident. Disappearance of ν_μ and appearance of ν_e is studied using all the data taken in the first experimental period from June 1999 to July 2001 (K2K-I) which corresponds to 4.8×10^{19} protons on target.

K2K uses an accelerator-produced neutrino beam with a neutrino flight distance of 250 km. The neutrino beam is produced by a 12 GeV proton beam from the KEK proton synchrotron. After the protons hitting an aluminum target, the produced positively charged particles, mainly pions, are focused by a pair of pulsed magnetic horns. The neutrinos produced from the decays of these particles are 98% pure muon neutrinos with a mean energy of 1.3 GeV. The pion momentum and angular distributions downstream of the second horn are measured with a gas-Cherenkov detector (PIMON) in order to verify the beam Monte Carlo (MC) simulation and to estimate the errors on the flux prediction at SK. The direction of the beam is monitored on a spill-by-spill basis by observing the profile of the muons from the pion decays with a set of ionization chambers and silicon pad detectors located just after the beam dump. The neutrino beam itself is measured in a set of near neutrino detectors (ND) located 300 m from the proton target. The measurements made at the ND are used to verify the stability and the direction of the beam, and to determine the flux normalization and the energy spectrum before the neutrinos travel the 250 km to SK. The flux at SK is estimated from the flux of the ND by multiplying the Far/Near (F/N) ratio, the ratio of fluxes between the far detector (SK) and ND, to that of the ND. The F/N is inferred by PIMON measurement. The ND is comprised of two detector systems: a 1 kiloton water Cherenkov detector (1KT) and a fine-grained detector (FGD) system. The flux normalization is measured by the

1KT to estimate the expected number of events at SK. Since the 1KT has the same detector technology as SK, most of systematic uncertainties on the measurement are canceled. The energy spectrum is measured by analyzing the muon momentum and angular distributions in both detector systems. In addition, the spectrum measurement by PIMON is used as a constraint. The MC calculation of the neutrion enerrgy spectrum agrees well with the data.

Since both a suppression in the number of events and a distortion of the spectrum are expected for neutrinos which travel a fixed path length in the presence of oscillations, both the number of observed events and the spectral shape information at SK are compared with expectation. All of the beam-induced neutrino events observed within the fiducial volume of SK are used to measure the overall suppression of flux. In order to study the spectral distortion, 1 ring μ-like events ($1R\mu$) are selected to enhance the fraction of charged-current (CC) quasi-elastic (QE) interactions ($\nu_\mu + n \rightarrow \mu + p$). Only the muon is visible in these reactions since the proton momentum is typically below Cherenkov threshold. The energy of the parent neutrino can be calculated by using the observed momentum of the muon, assuming QE interactions, and neglecting Fermi momentum.

The events in SK are selected using the timing information provided by the global positioning system. Events detected in SK must occur within an expected beam arrival time window of 1.5 μsec. In addition, the detected events must have no activity in outer detector, and have an energy deposit greater than 30 MeV with a vertex reconstructed within the 22.5 kiloton fiducial volume. This sample of events is referred to as the fully contained (FC) sample. The efficiency of this selection is 93% for CC interactions. Fifty-six events satisfy the criteria, while the expected number of FC events at SK without oscillation is estimated to be $80.1^{+6.2}_{-5.4}$. With the timing cut, the expected number of atmospheric neutrino background is approximately 10^{-3} events. The correlations between energy bins from the spectrum measurement at the ND and the F/N ratio are taken into account in the estimation of the systematic errors. The major contributions to the errors come from the uncertainties in the F/N ratio ($^{+4.9\%}_{-5.0\%}$) and the normalization (5.0%), dominated by uncertainties of the fiducial volumes due to vertex reconstruction both at the 1KT and SK.

A two flavor neutrino oscillation analysis, with ν_μ disappearance, is performed by the maximum-likelihood method. In the analysis, both the number of FC events and the energy spectrum shape for $1R\mu$ events are used. The likelihood is calculated at each point in the Δm^2 and $\sin^2 2\theta$ space to search for the point where the likelihood is maximized. The best fit point in the physical region of oscillation parameter space is found to be at ($\sin^2 2\theta$, Δm^2)=$(1.0, 2.8 \times 10^{-3}$ eV^2). If the whole space including the unphysical region is considered the values are $(1.03, 2.8 \times 10^{-3}\ \mathrm{eV}^2)$. At the best fit point in the physical region the total number of predicted events is 54.2, which agrees with the observation of 56 within statistical error. The best fit spectrum shape agrees with the observations.

The probability that the observations are due to a statistical fluctuation instead of neutrino oscillation is estimated by computing the likelihood ratio of the no-oscillation case to the best fit point. The no-oscillation probabilities are calculated to be 0.7%. When only normalization (shape) information is used, the probabilities are 1.3% (16%). Allowed regions of oscillation parameters are evaluated by calculating the likelihood ratio of each point to the best fit point. The 90% C.L. contour crosses the $\sin^2 2\theta = 1$ axis at 1.5 and $3.9 \times 10^{-3}\ \mathrm{eV}^2$ for Δm^2. The oscillation parameters preferred by the total flux suppression and the energy distortions alone also agree well.

Appearance of ν_e is also searched for in the K2K-I data set. Fully contained one ring e-like events were selected by utilizing ring pattern and the opning angle information. After the selection, only one event out of 56 fully contained events remains. The main background comes from the ν_μ interacitons of which the neutral current π^0 production is dominant. Excluded region in the Δm^2 and $\sin^2 2\theta$ space is consistent with CHOOZ which studied ν_e disappearance.

V. Astrophysics group

(*T.Hayashino, Y.Matsuda, H.Tamura, R.Yamaguchi, M.Kurata, H.Usami*)

We have revealed in our deep and wide($32' \times 24'$) Lyα survey with Subaru prime focus camera(Suprime-Cam) applying a narrowband filter NB497 (CW497nm/BW8nm to find $z = 3.09$ Lyα) that the high density region of Lyman break galaxies(LBGs) and Lyα emitters found by Steidel et al. (Astrophysical Journal, 532 (2000)) at redshift 3.09 in SSA22a field with 8.'7×8.'9 area, widely extends to outside of the original field. The high density region of 283 strong Lyα emitters detected in the present survey shows a belt-like large structure 60 Mpc long by 15∼20 Mpc wide in comoving scale. Also, another rather orthogonal belt 30 Mpc long by 15 Mpc wide from the field center to NE is recognized. (Totally flat WMAP cosmology(Ω_{M}=0.3, Ω_Λ=0.7, and $H_0 = 70\ h_{70}$ km s^{-1} Mpc^{-1}) is adopted.) The large scale structure found would be very rare event with the appearance probability of only 0.15% even if a rather large bias parameter of "4" is assumed. In addition to a number of Lyα emitters, strong Lyα absorbers, which are possibly Lyman break galaxies(LBGs) at $z = 3.09$ and extended Lyα sources, mini-blobs are found in the high density region as well as two giant Lyα blobs already discovered by Steidel et al.. Such high concentration of Lyα objects strongly indicates the large structure to be a "Giant Galaxy-Forming Region" probably filled with rich neutral hydrogens, where many kinds of primeval objects are forming. Interestingly, the strong Lyα emitters are found to randomly distribute in the belt-like high density region from angular two point correlation analysis of the emitters belonging to the high density region.

The large scale structure found would be only a part of huge structure, because the belt-like structures reach the edge of the present FoV. They will probably extend to the next FoV. Moreover, these belts can be a slice of huge sheets and similar belts may appear in foreground or background narrowband slice. Therefore, it is necessary to carry out a successive survey around this field to examine three dimensional extension of the belt-like structures and determine a characteristic scale of the structure. In this summer, we are going to observe the north-west field contiguous to the present one applying NB497 filter. Three dimensional mapping of high redshift objects in large scales should offer valuable information on structure formation in the universe.

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<u>Doctor Thesis</u>

D1) *Search for Electron Anti-Neutrino from the Sun using the KamLAND Large Volume Liquid Scintillator Detector.*
Hiroshi Ogawa (2003.10)

D2) *Measurement of sin*$(2\phi_1)$ *using* $J/\psi K_L^0$ *decay of B mesons.*
Itaru Higuchi

D3) *A Search for Anti-electron-neutrinos from the Sun at Super-Kamiokande.*
Yoshihito Gando

<u>Master Thesis</u>

M1) *Study of light emission properties of liquid scintillator for low enerty electrons.*
Koji Eguchi (2003.6)

M2) *Study of background below 1MeV for KamLAND experiment*
Tatsuo Maeda

M3) *Study of liquid scintillator purification for low energy solar neutrino observation.*
Yotaro Koseki

M4) *Search for super nova relic neutrinos with KamLAND.*
Kenichi Tada

M5) *Development of water-based liquid scintillator.*
Kentaro Owada

M6) *Measurement of* D_s^* *polarization in* B *meson decays.*
Takahiro Kato

M7) *Search for Pair Galaxies by the Cosmic String with Subaru telescope.*
Ryosuke Yamauchi